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Research on Producing Low-power Low-voltage DC Power Supply with High-voltage Power Bus

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Abstract

The online monitoring equipment installed on the high-voltage power bus is supported by reliable and stable DC power, which cannot be obtained from industrial low-voltage AC power or chemical battery. This paper presents a circuit based on the principle of electromagnetic induction to obtain low-voltage low-power DC power supply from high voltage power bus. The circuit consists of energy-acquired coil, the rectifier and regulator circuit, and the shunt coils. This power supply can work with small current in the bus, also it can output stable DC voltage in the case of large current in the bus by starting shunt coil. The experimental data indicates that the output voltage of the power supply are 3.3V and 5V, the output power is greater than 120 mW and the bus starting current is less than 5A, all these can suffice for the online monitoring equipment.

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Keywords: High-voltage power bus; DC power supply; Shunt coil

1. Introduction

In order to ensure the safety of power systems' operation, more and more monitoring equipment need to be installed directly on the high-voltage power bus to monitor in real-time, the typical representations are the electronic current transformer and online bus-temperature-monitoring equipment. All these devices are driven by low-voltage DC power supply. According to the rules of national power system, low voltage electricity is not allowed to feed directly from the high side bus. Earlier power supply such as chemical and optical battery proved to be short-lived and unreliable [1], so it's essential to develop low-voltage DC power supply for these devices by directly using of high voltage power bus [1]–[2].

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2. Key Issues and Design Goal

As high-voltage power is transferring through the AC bus, it will produce an alternating magnetic field around. We can design a coil to induce the alternating current from the magnetic field, and then gain the DC voltage through the rectifier and regulator [1]–[4]. This is the basic idea of obtaining the DC power from high-voltage bus.

2.1. Key issues

The following issues need to be addressed because of the complex situation that high voltage bus current changes significantly.

1) The selection of core material. Since the core can excite on the condition that the current in the bus is small but will saturate when the current is large, it is required that the transformer core has relatively small saturated magnetic induction, small eddy current and hysteresis loss, to enhance the thermal stability of the core when long-term used in saturation.

2) The operating state when small current in the bus [4]. As the current in the power bus ranges from a few amperes to hundreds of amps--almost 100 times' change, the operating state of the DC power supply designed should be considered to see whether it can provide sufficient voltage and power for monitoring equipment in case of it works with small current in the bus.

3) The operating state when large current in the bus [4]. When the bus current is large, the core may produce generate heat because of saturation, and the voltage of the DC power supply designed will increase.

4) The operating state when the bus is in short circuit, surges, or lightning strikes [1] [4]. When short circuit, surge, lightning strike occurs, it's essential to take reasonable protective measures to avoid the damage of the monitoring equipment.

To sum up: the key problems followed should be solved: the first one is how to minimize the current of the dead zone to provide sufficient power to drive the monitoring equipment in the high-voltage side when the current of the power system is small; and the second one is how to provide stable power supply which can absorb the excess power and cannot be damaged when overvoltage for the monitoring equipment.

2.2. Design goal

The following design goals proposed based on statistics of the input power of the Electronic Current Transformer.

1) Output voltage 3.3V, 5V.

2) Output power > 120mw.

3) Bus starting current < 5A.

3. Circuit Design

3.1. Circuit diagram

The circuit diagram is shown in Fig. 1.

The circuit includes energy-acquired coil, the control shunt coil, rectifier filter circuit, voltage regulator circuit, control circuit, diode protection circuits, lightning protection circuit, and super capacitors.

The energy-acquired coil inducts a certain degree of AC power from the high voltage bus by electromagnetic induction.

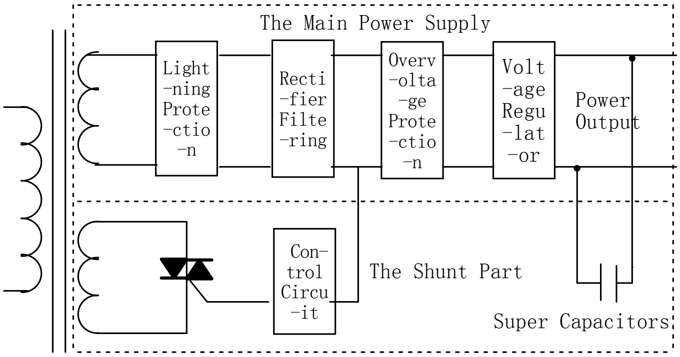

Fig. 1. Circuit Diagram

The control shunt coil is mainly used when large current go through the high voltage bus to reduce the magnetic flux in the core and the voltage which the energy-acquired coil inducts, with the means of controlling the conduction of the coil by the control circuit[5], based on the principle of magnetic potential.

The regulator circuit transforms the input voltage from DC 9V-16V into 3.3V and 5V with the voltage regulator chip.

The lightning protection circuit is to avoid the power circuit damage caused by thunder impact.

The super capacitor plays as backup power under special circumstances such as bus open circuit.

3.2. Design of the core and coil

The selection of the core and design of coil turns are in accordance with theoretical calculations and then adjusted according to the engineering experiment.

According to the market research and engineering experiments, the core which is 0.35mm thick and made up of EI 15 types of cold-rolled silicon steel sheet is proper. Core cross-sectional area (chip number) size, can be seen as the transformer in theoretical calculations, and then determined by the width of the bus and engineering experiments. In accordance with the design goal, the cross-sectional area is about 10mm×15mm.

There are many influencing factors in the core design, such as core shape, filling quotient, stacking coefficient, process factor, temperature coefficient and the wear and tear; also there exists factors such as the material of the wire, density of current, arrangement of loops, impedance, loss and temperature effects in the secondary winding; and what's more, in the production of coils and winding, there are some subtle differences between bound and a variety of defects. So for the coil design, particularly the determination of secondary turns can only be given in accordance with (1) for a rough estimation methods, and actual turns determined by the circuit debugging.

$$N = \frac{E}{4.44 f B_s A_C} \tag{1}$$

where f represents frequency (50Hz), B_s represents magnetic induction of silicon steel (about 1.5T), and A_C represents the cross-sectional area of the core.

3.3. Design of DC power supply

The AC power inducted from the high voltage bus by the coils need to be transformed into DC power to supply the monitoring equipment with the DC voltage regulator circuit. The DC power supply generally consists of the following four parts: the transformer, rectifier, filter circuit and the voltage regulator circuit, as shown in Fig. 2. And it performs with full-bridge rectifier and capacitor filter. The chip SPX5205-3.3 made by the SIPEX Corporation is called in the 3.3V buck regulator circuit. SPX5205 (TSO-23 5PIN chip packaged) is a chip with low-cost, low-noise LDO buck converter which can provide 150mA output current maximum. Its maximum absolute voltage difference is 210mv, quiescent current is 70μA, input voltage is 2.5V~16V. A high-frequency capacitance is connected in parallel with the power supply output to reduce the impact the regulator chip made on the power supply voltage. 5V buck regulator circuit uses SPX29300-5.0(TO-263 3PIN chip packaged) made by the SIPEX Corporation, SPX29300 is a low-cost, low-noise LDO buck converter chip, the maximum available output current is 3A, low dropout voltage is 550mV, quiescent current is 900μA, the input voltage is 2.5V ~ 16V.

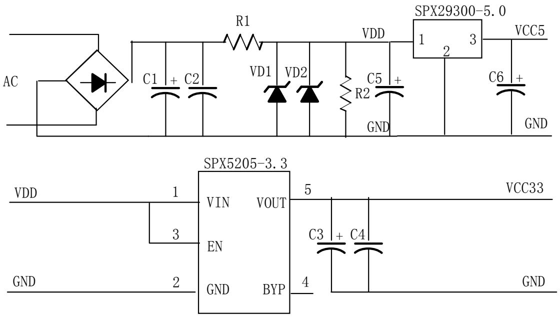

Fig. 2. Design of DC Power Supply

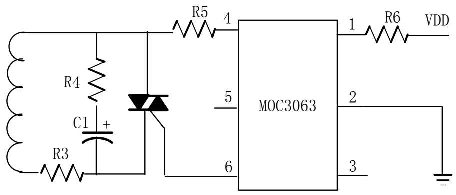

Fig. 3. Design of The Shunt Circuit

3.4. Design of the shunt circuit

The large range of the current (a few to thousands Amp) in the bus or the circuit caused by the significant changes in the power system makes the design of the regulated power more difficult. To solve the problem, shunt circuit is designed to guarantee stable and reliable work of the main circuit which provides power to the high-voltage circuit. The key component of the circuit is triac which mainly provides the zero-turn-off function. Series of optoelectronic MOC3063 triac driver made by Motorola is selected to be control switching component of the shunt coil.

When the current in the bus is large enough, the power inducted by the energy-acquired coil increases, and the voltage and current of input No.1 of MOC3063 operates, the output of MOC3063 made the triac turn on, then shunt coil will work according to the balance of magnetic energy to reduce the power induced in the energy-acquired coil, thus the following regulated circuit will be protected after the reducing of the input voltage of the regulated chip. The controlled shunt circuit is shown in Fig. 3.

3.5. Circuit protection

The circuit protection is an important guarantee of the supply's security as the high side circuit and power supply work in the outdoor environment. The protection should consider the lightning protection, surge capabilities. Bipolar and unipolar transient suppression diode TVS are used as lightning and surge protection devices in recent study [1] [4]. When lightning shocks, it can transform the bipolar high impedance lower with 1×10E-12s rate to strangle the bipolar voltage coincident with choice value and absorb the surge power to avoid the damage caused by lightning impulse.

4. Experimental Data Analysis and Conclusions

To test the performance of the designed power supply, an experimental platform with large current is built. Actually, the high voltage bus site can't be perfectly simulated with the conditions in the laboratory, but it's viable to infer the follow-up work according to fitting the curve.

4.1. The number of turns

Test conditions: bus current is 8A, load is 75Ω. The relationship between the number of turns and the voltage output is shown in Table 1. According to analysis of the measured data, 75 is selected to be the actual turns of the energy-acquired coil.

4.2. Launch conditions shunt coil

Theoretical analysis shows that when bus current increases, the power induced current will increase, while the rectifier output voltage also increases, if the bus current increase to a certain extent, the rectifier output voltage continues to increase, the follow-up voltage regulator may be burned. So it's necessary to launch the control shunt coil to reduce the input voltage of the regulator circuit to protect the follow-up regulator circuit.

Table 2 shows the relationship between the bus current and output voltage with 75Ω load. It's cognoscible from the curve fitted by Matlab that the current is about 200A in the high voltage cable, the output voltage electromagnetic induction coil achieved reach to 16V which may burn the voltage regulator. So it's required to activate the shunt coil to reduce the input voltage of the regulator circuit to protect the voltage regulator circuit.

Table 1: The number of turns and the voltage output

ID	Number of turns	Voltage output (V)
1	35	3.8
2	55	3.9
3	65	4.1
4	75	4.2
5	95	3.9

Table 2: The bus current and the voltage output

ID	Bus current (A)	Voltage output (V)
1	10	4.4
2	20	5.3
3	30	6.3
4	40	7.1
5	50	7.9
6	60	8.5
7	70	9.1
8	80	9.7
9	90	10.2
10	100	10.8
11	110	11.2
12	120	11.7
13	130	12.1
14	140	12.6

5. Conclusion

The experiments prove that the electromagnetic induction power such as current transformer can provide low-power low-voltage DC supply for the equipment monitoring on high-voltage side of the bus. The power supply can work safe and reliable when the bus current is small, while it can launch the shunt coil to resolve core saturation fever problems and protect the power circuit and follow-up equipment when the bus current is large. But the number of turns and the value of the bus current to launch the shunt coil rely on engineering experiment.

However, the circuit design has its own flaws, firstly, launching current dead zone exists, when the bus current is less than 5A, the output voltage is unstable; secondly, the shunt coil needs adequate space for heat dissipation when bus current is too large.

Acknowledgements

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